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(54) BRUSHLESS DIRECT CURRENT MOTORS

(71) We, SONY CORPORATION, a corporation organised and existing under the laws of Japan, of 7–35 Kitashinagawa–6, Shinagawa-–ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:–

This invention relates to brushless direct current motors, and more particularly, but not exclusively to brushless direct current motors suitable for magnetic tape recorders of the capstan direct drive type.

Brushless *dc* motors are widely used in acoustic apparatus, such as a tape recorder, as a brushless *dc* motor rotates quietly, in contrast to a *dc* motor having brushes. However, most brushless *dc* motors are relatively large in the axial direction. In such a brushless *dc* motor, the direction of the magnetic field is perpendicular to the rotary shaft, and it is difficult to manufacture a flat brushless *dc* motor as this reduces the length of the energized conductor which generates the rotational force.

A relatively flat brushless *dc* motor has however been proposed in US patent no. 3 912 956, in which a magnetic field parallel to the rotary shaft is applied to the energized radially extending conductor. The magnetic field can be effectively applied to the energized conductor to convert electrical energy to mechanical energy even if the brushless *dc* motor has a small axial length. The motor is simple in construction, and has a long life-time. Since the motor can be flattened, high inertia can be obtained. The general characteristic is low speed-high t rque.

However, this motor has the disadvantages that the assembly is troublesome, the efficiency is not satisfactory, and the support for the rotary shaft is unstable.

According to the present invention there is provided a brushless *dc* motor comprising-

a stator member;

a stationary cylindrical member mounted on said stator member and having bearings on its inner circumferential surface;

a rotary shaft rotatably supported by said bearings of said stationary cylindrical member;

a rotary cylindrical member into which said stationary cylindrical member projects, and to which said rotary shaft is fixed;

at least two rotary discs of magnetic material, fixed to said rotary cylindrical member and spaced from each other;

at least one permanent magnet fixed to one of said rotary discs;

a rotational-position detecting member arranged on said stator member to detect the angular position of said rotary discs; and

a coil assembly arranged on said stator member, including a plurality of coil units arranged to be selectively energized in response to the output of said rotational-position detecting member;

the arrangement of said rotary shaft being such that in use of the motor the drive from said rotary shaft is derived from that end of said rotary shaft which is nearer to said stationary cylindrical member than to said rotary cylindrical member.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a plan view of the whole of a brushless direct current motor according to one embodiment of this invention;

Figure 2 is a cross-sectional view taken along the line II–II of Figure 1;

Figure 3A and Figure 3B are a cross-sectional view and an elevational view of an upper casing of the motor f Figure 2, respectively;

Figure 4 and Figure 5 are plan views of examples of permanent magnets which can be employed for one embodiment of this invention, of which the permanent magnet of Figure 4 is employed for this embodiment;

Figure 6A is a plan view of a lower rotary ring assembly of the motor of Figure 2;

Figure 6B is a cross-sectional view taken along the line VIB–VIB of Figure 6A;

Figure 7 is a cross-sectional view showing the lower rotary ring assembly of Figure 6B provided with a rotary cylindrical member;

Figure 8 is a cross-sectional view of a rotor assembly of the motor of Figure 2;

Figure 9 is an exploded perspective view of an important part of the rotor assembly of Figure 8, in which paths of magnetic flux are shown;

Figure 10 is an enlarged perspective view of a coil unit to be applied to the coil assembly of the motor of Figure 2;

Figure 11 is a cross-sectional view taken along the line XI–XI of Figure 10;

Figure 12 is an enlarged perspective view of the coil assembly of the motor of Figure 2;

Figure 13 is a cross-sectional view taken along the line XIII–XIII of Figure 12;

Figure 14 is a cross-sectional view of a rotor-stator assembly of the motor of Figure 2;

Figure 15 is an enlarged plan view of a rotational-position detecting plate of the motor of Figure 2;

Figure 16A and Figure 16B are a plan view and an elevational view of a lower casing of the motor of Figure 2;

Figure 17 is a circuit diagram of a drive circuit for the motor of Figure 2;

Figure 18 is an enlarged perspective view of a part of the motor of Figure 2;

Figure 19 is a circuit diagram of a conventional brush-less direct current motor for explaining the advantage of the drive circuit of Figure 17;

Figure 20 is a circuit diagram equivalent to the circuit of Figure 19;

Figure 21 is a graph showing the output characteristics of the conventional motor;

Figure 22 is a graph showing the output characteristics of the motor according to one embodiment of this invention;

Figure 23 is a schematic plan view of a tape recorder to which the motor according to one embodiment will be applied;

Figure 24 is a cross-sectional view of one modification of the motor of Figure 2;

Figure 25 is a plan view of one modification of the coil assembly of Figure 12;

Figure 26 is a cross-sectional view taken along the line XXVI–XXVI of Figure 25;

Figure 27 is a cross-sectional view showing the coil assembly of Figure 26 attached to the upper casing, which corresponds to Figure 14;

Figure 28 is a plan view f a part of a further modification of the coil assembly of Figure 12;

Figure 29 is a plan view of another part of the modification of Figure 28;

Figure 30A and Figure 30B are cross-sectional views taken along the lines XXXA–XXXA and XXXB–XXXB of Figure 28 and Figure 29, showing the assembling step of the modification of Figure 28 and Figure 29;

Figure 31 is a plan view of the modification of the coil assembly;

Figure 32 is a cross-section view taken along the line XXXII–XXXII of Figure 31.

Figure 33 is a partly broken-away plan view of one modification of the coil assembly of Figure 31;

Figure 34 is a plan view of a part (coil-mounting plate) of a further modification of the coil assembly of Figure 31;

Figure 35 is a perspective view showing the coil-mounting plate of Figure 34 being bent; and

Figure 36 is a circuit diagram of one modification of the drive circuit of Figure 17.

A flat brushless direct current motor according to one embodiment of this invention, which is applied to a magnetic tape recorder, will be described with reference to the drawings.

Figure 1 is a plan view of a flat brushless *dc* motor M, and Figure 2 is a cross-sectional view, taken along the line II–II of Figure 1. Next, the construction of the motor will be described in the sequence of the assembling steps.

Referring to Figure 1 to Figure 3, an upper casing 1 is manufactured of soft magnetic material (mainly Fe-group), and functions as an electro-magnetic shielding member to the exterior. Larger and smaller cut-out portions 2 and 3 conjoined with each other are formed in a stepped circumferential surface 1*a* of the upper casing 1. A stationary cylindrical member 4 is press-fitted to a central opening of the upper casing 1. Th cylindrical member 4 is formed, for example, of soft magnetic material. Cylindrical bearings 5 and 6 formed of oleo sintered copper alloy are fixed to the upper and lower inner surfaces of the stationary cylindrical member 4. The cylindrical member 4 fitted to the upper casing 1 is centred relative to the bearings 5 and 6.

Figure 4 and Figure 5 show permanent magnets 7 and 7′ which may be alternatively employed for this embodiment. The permanent magnet 7 of Figure 4 consists of four magnetized sectors. The permanent magnet 7′ of Figure 5 consists of a four-pole magnetized ring. The permanent magnet 7 of Figure 4 is used in this embodiment.

Next, a lower rotary ring assembly 10 will be described with reference to Figure 6A and Figure 6B.

The sector magnets 7 are positioned at angularly regular intervals by a positioning ring 8 formed of dimensionally accurate electric-insulating material, for example, a bulk mould

compound material. The N-pole sector magnet 7 and the S-pole sector magnet 7 are alternately arranged. The positioning ring 8 is provided with four inward projections 8C. The respective sector magnets 7 are fitted between the projections 8C. A lower rotary ring 9 of soft magnetic material (mainly Fe-group) is fixed to the lower surfaces of the sector magnets 7 and to the inner circumferential surface 8*b* of the positioning ring 8. Thus, the lower ring assembly 10 is obtained. Teeth 8*a* for rotational speed detecting are made in the outer circumferential surface of the positioning ring 8. Metal is vapour-deposited or plated on the teeth 8*a*. When the magnet 7' of Figure 5 is used in this embodiment, the inward projections 8C are omitted from the positioning ring 8.

Next, a rotary cylindrical member 11 shown in Figure 7 is press-fitted to the central opening of the lower rotary ring 9 of the lower rotary ring assembly 10 shown in Figure 6A and Figure 6B. The rotary cylindrical member 11 is made of non-magnetic material such as brass.

Then, after the rotary cylindrical member 11 is inserted into a coil assembly 12 shown in Figure 12 to be described hereinafter in detail, an upper rotary ring 13 made of soft magnetic material is fixed at its inner circumferential surface to an upper end surface 11*a* of the rotary cylindrical member 11 by screws. A rotary shaft 14, namely a capstan shaft in this case is fixed to a central opening 11*b* of the rotary cylindrical member 11. Thus, a rotor assembly 15 except the coil assembly 12 is obtained as shown in Figure 8.

The paths of magnetic flux in the thus obtained rotor assembly 15 are shown by the dotted lines in Figure 9. As shown in Figure 9, the magnetic flux starting from the N-pole flows substantially in parallel with the capstan shaft 14, not shown in Figure 9, flows through the upper or lower rotary ring 13 or 9 and then flows substantially parallel with the capstan shaft 14 to terminate at the S-pole.

Next, the detail of the coil assembly 12 will be described with reference to Figure 10 to Figure 13.

As clearly shown in Figure 12, the coil assembly 12 comprises six substantially sectorial coil units 20*a*, 20*b*, 21*a*, 21*b*, 22*a*, and 22*b* for the four-pole magnet, a printed plate 23, and a coil-positioning ring 24. The printed plate 23 comprises a projecting terminal portion 23*a* for electrically connecting the coil units 20*a* to 22*b* to a drive circuit, and a lead-connecting ring portion 23*c* for connecting the lead terminals of the coil units to the printed plate 23 on which necessary circuits are printed and insulated. The diameter of the central opening 23*d* of the printed plate 23 is smaller than that of the central opening 24*a* of the coil-positioning ring 24. The printed plate 23 and the coil-positioning ring 24 are fixed to each other by adhesive in such a manner that the central opening 23*d* and 24*a* of the printed plate 23 and coil-positioning ring 24 are concentric with each other. A circular recess is formed by the lower surface f the printed plate 23 and the inner circumferential surface of the coil-positioning ring 24. The six coil units 20*a* to 22*b* are positioned by the circular recess. The six coil units 20*a* to 22*b* are equally divided into upper and lower groups, and the coil units of the upper group are overlapped on those of the lower group so that the six coil units are arranged at angularly regular intervals of 60 degrees. The outer circular surfaces of the coil units are contacted with the inner circumferential surface of the coil-positioning ring 24. The coil units 20*a* and 20*b* are arranged diametrically to each other. Similarly, the coil units 21*a* and 21*b*, and 22*a* and 22*b* are arranged diametrically to each other, respectively.

One coil unit is shown enlarged in Figure 10. It is formed by winding a conductive wire of the flat type, the cross-section of which is shown in Figure 11. Such a wire is generally called, "oval wire" or "stream-lined wire". As shown in Figure 11, an insulating layer 26 is deposited on a conductive core 25 formed of copper, and further a meltable insulating layer 27 is deposited on the insulating layer 26, in the conductive wire. The sectorial coil unit after being wound is hardened with heat or chemical solvent.

The six coil units 20*a* to 22*b* thus manufactured are so positioned, as above described, in the coil assembly 12. Double the thickness of one coil unit is slightly smaller than the thickness of the coil-positioning ring 24, as shown in Figure 13. The coil units 20*a* to 22*b* are fixed at the overlapping portions to each other, and further fixed to the inner circumferential surface of the coil-positioning ring 24 and the lower surface of the printed plate 23, by adhesive. Thus, the whole coil assembly 12 is reinforced with such fixation and the coil-positioning ring 24.

The initial ends ℓ of the conductive wires of the coil units and the terminal ends *m* thereof are soldered to the circuit (partially shown in Figure 12) printed on the lead-connecting ring portion 23*c* of the printed plate 23. Screw holes 23*b* for fixing the coil assembly 12 to the upper casing 1 are made in the periphery of the coil assembly 12. The printed circuits are insulated in the conventional manner.

After the coil assembly 12 is arranged in the position shown in Figure 8, the stationary cylindrical member 4 fixed to the upper casing 1 (Figure 3A and Figure 3B) is inserted into the rotary cylindrical member 11 assembled in the rotor assembly 15 (Figure 8), and the capstan shaft 14 is inserted through the stationary cylindrical member 4 to be rotatably supported in the bearings 5 and 6. The coil assembly 12 is fixed to the upper casing 1 by means of the screw holes 23*b*. The projecting terminal portion 23*a* of the printed plate 23 of the coil assembly 12 is projected through the cut-out

portion 2 made in the stepped circumferential surface $1a$ of the upper casing 1, as shown in Figure 1 and received by the cut-out portion 2.

Thus, a rotor-stator assembly 29 shown in Figure 14 is obtained. A rotational-position detecting plate 30 shown in Figure 15 is further assembled into the assembly 29 in such a manner that the detecting plate 30 is contacted with the lower surface of the coil-positioning ring 24. The necessary circuit is printed on the detecting plate 30, which is substantially in fork-like shape, and comprises a projecting terminal portion $30a$ and a circular-arc shaped guide portion $30b$. Three position detecting elements, for example, Hall-elements $31a$, $31b$ and $31c$ are fixed on the guide portion 30b at angular intervals of 60 degrees round the capstan shaft 14, which is not shown in Figure 15. Since the detecting plate 30 defines a cut-out portion $30d$, it can be inserted into the rotor-stator assembly 29 of Figure 14 under the coil assembly 12, and it is radially positioned at the periphery $30c$ by the inner circumferential surface $1b$ of the upper casing 1. The projecting terminal portion $30a$ of the detecting plate 30 is passed through the cut-out portions 2 and 3 made in the stepped circumferential surface $1a$ of the upper casing 1 which portions communicate with each other. As clearly shown in Figure 1, it projects from the upper casing 1. Accordingly, the detecting plate 30 can be easily slid in the peripheral direction within the range of the cut-out portions 2 and 3.

While the rotor assembly 15 is rotated with the energization of the coil units—the principle of the motor drive will be described hereinafter—, the angular position of the detecting plate 30 is adjusted. The detecting plate 30 is fixed relative to the upper casing 1 at the position at which the current flowing through the coil units is at the minimum. The fixing of the detecting plate 30 may be effected in a suitable manner. For example, it may be effected in such a manner that screws are inserted through oblong holes (not shown) made in the guide portion $30b$ of the detecting plate 30 to be engaged with threaded holes (not shown) made in the coil-positioning ring 24 of the coil assembly 12 which is already fixed to the upper casing 1. Or it may be effected in such a manner that a ring member 39 (shown in Figure 2) made of insulating material and arranged under the detecting plate 30 is screwed to the inner circumferential surface $1b$ of the upper casing 1 to press the detecting plate 30 between the coil assembly 12 and the insulating ring member 39. The motor can be driven at the optimum condition by the above described angular adjustment of the detecting plate 30.

After the detecting plate 30 is assembled into the rotor-stator assembly 29 of Figure 14, a pair of stator-side speed-detecting ring heads 37 made of metal (shown in Figure 2) and insulated from each other by an insulating ring 36 having T-shaped cross-section is fixed to the insulating ring member 39 which is already fixed relative to the upper casing 1. Teeth 38 are made in the inner circumferential surfaces of the stator-side speed detecting ring heads 37, and are opposed to the teeth $8a$ of the positioning ring 8.

Next, a lower casing 32 shown in Figure 16A and Figure 16B is engaged with the upper casing 1 into which the different parts are already assembled. The lower casing 32 is made of soft magnetic material like the upper casing 1. A circular cut-out portion $32a$ is made in the periphery of the lower casing 32, and it is fitted to the stepped portion $1c$ in the stepped circumferential surface $1a$ of the upper casing 1 to engage the lower casing 32 with the latter. Further, a cut-out portion $32b$ is made in the upper edge of the lower casing 32. When the lower casing 32 is engaged with the upper casing 1, the cut-out portion $32b$ is communicated with the cut-out portions 2 and 3 of the upper casing 1 from which the projecting terminal portions $23a$ and $30a$ of the coil assembly 12 and the rotational-position detecting plate 30 are projected as shown in Figure 1. An adjusting screw 35 is fitted to the centre of the bottom of the lower casing 32. The vertical position of the rotor assembly 15 is adjusted with the rotation of the adjusting screw 35. Thus, the assembling of the flat brushless *dc* motor M is completed.

Next, the principle of the motor drive will be described.

There will be considered the case that the rotational-position detecting plate 30 is so attached to the coil assembly 12 that the Hall elements $31a$, $31b$ and $31c$ of the detecting plate 30 correspond to the coil units $22a$, $21b$ and $20a$ (see Figure 12 and Figure 15), respectively. Leakage magnetic flux from the permanent magnet 7 fixed on the lower rotary ring 9 is sensed by the detecting plate 30. The first Hall element $31a$ detects that the leakage magnetic flux in one direction is applied to the coil unit $22a$. A first electronic switching element (hereinafter described) is turned on with the detecting output of the first Hall element $31a$, to pass such a current through the coil unit $22a$ and the coil unit $22b$ arranged diametrically to the coil unit $22a$ as to impart the rotational forces in the same direction to the rotary assembly 15. When the rotary assembly 15 further rotates by 60 degrees, the leakage magnetic flux in the one direction is applied to the second Hall element $31b$. A second electronic switching element is turned on, while the first electronic switching element is turned off, with the detecting output of the second Hall element $31b$. Such a current is passed through the coil unit $21b$ and the coil unit $21a$ arranged diametrically to the coil unit $21b$ as to impart the rotational forces in the same direction to the rotary assembly 15. When the rotary assembly 15 further rotates by 60 degrees, the leakage magnetic flux in the one direction as

above described is applied to the third Hall element 31*c*. A third electronic switching element is turned on, while the second electronic switching element is turned off, with the detecting output of the third Hall element 31*c*. Such a current is passed through the coil unit 20*a* and the coil unit 20*b* arranged diametrically to the coil unit 20*a* as to impart the rotational forces in the same direction to the rotary assembly 15. And when the rotary assembly 15 still further rotates by 60 degrees, namely rotates by 180 degree from the initial position at which the leakage magnetic flux in the one direction is applied to the coil unit 22*a*, the leakage magnetic flux in the same direction as the above-described one direction is again applied to the first Hall element 31*a* and the coil unit 22*a*, since the permanent magnet sectors 7 of the same polarity are arranged diametrically to each other as clearly shown in Figure 6A. Thus, the above-described operations are repeated. Each of the coil units is energized twice for each revolution of the rotor assembly 15, with the change-over of the three electronic switching elements to continue the rotation of the rotary assembly 15.

A drive circuit shown in Figure 17 is used for the above-described brushless *dc* motor M which is applied to a tape recorder. Next, the circuit of Figure 17 will be described.

In the circuit of Figure 17, transistors Q_1, Q_2 and Q_3 function as the above-described first, second and third electronic switching elements. The bases of the transistors Q_1, Q_2 and Q_3 are electrically connected to the terminal portion 30*a* of the rotational-position detecting plate 30 of Figure 15. The emitters of the transistors Q_1, Q_2 and Q_3 are connected in common with a battery E_0 as a *dc* voltage source. Stationary contacts a_1, a_2, and a_3 of motor starting/stopping switches S_7, S_8 and S_9 are connected to the collectors of the transistors Q_1, Q_2 and Q_3, respectively. Other stationary contacts b_1, b_2 and b_3 of the motor starting-stopping switches S_7, S_8 and S_9 are connected to stationary contacts d_1, d_2 and d_3 of first series-parallel change-over switches S_1, S_3 and S_5, and to terminals of the coil units 22*b*, 21*b* and 20*b*, respectively which are connected in common with each other. Movable contacts of the motor starting/stopping switches S_7, S_8 and S_9 are connected to terminals of the coil units 22*a*, 21*a* and 20*a*, and to stationary contacts e_1, e_2 and e_3 of second series-parallel change-over switches S_2, S_4 and S_6, respectively. Other terminals of the coil units 22*a*, 21*a* and 20*a* are connected to movable contacts of the first series-parallel change-over switches S_1, S_3 and S_5. Other stationary contacts c_1, c_2 and c_3 of the first series-parallel change-over switches S_1, S_3 and S_5 are connected to other stationary contacts f_1, f_2 and f_3 of the second series-parallel change-over switches S_2, S_4 and S_6. Movable contacts of the second series-parallel change-over switches S_2, S_4 and S_6 are connected to other terminals of the coil units 22*b*, 21*b* and 20*b*, respectively.

The common terminals of the coil units 22*b*, 21*b* and 20*b* are connected to the collector of a control transistor Q_4. A speed control circuit 50 is connected to the base of the control transistor Q_4. The emitter of the control transistor Q_4 is connected to the battery E_0.

The movable contacts of the motor starting/stopping switches S_7, S_8 and S_9 are ganged with each other, and actuated by a common start/stop slide switch SW_2 shown by the dotted lines in Figure 17 which is arranged, for example, on the terminal portion 23*a* of the printed plate 23 of the coil assembly 12 in the manner shown in Figure 18. The movable contacts of the switches S_7, S_8 and S_9 are simultaneously connected to the first stationary contact a_1, a_2 and a_3 or to the second stationary contacts b_1, b_2 and b_3, by the common start/stop slide switch SW_2.

The movable contacts of the series-parallel change-over switches S_1 to S_6 are ganged with each other, and actuated by a common series-parallel change-over slide switch SW_1 shown by the dotted line in Figure 17 which is arranged at the side of the slide switch SW_2, for example, on the terminal portion 23*a* of the printed plate 23 of the coil assembly 12 in the manner shown in Figure 18. The movable contacts of the switches S_1 to S_6 are simultaneously connected to the first stationary contacts c_1, f_1, c_2, f_2, c_3 and f_3 or to the second stationary contacts d_1, e_1, d_2, e_2, d_3 and e_3 by the common series-parallel change-over slide switch SW_2.

The slide switches SW_1 and SW_2 can be manually operated by knobs 40 and 41. However, the knobs 40 and 41 of the slide switches SW_1 and SW_2 may be interconnected with a reproducing push-button, a fast-forwarding push-button, a rewind push-button, and a stop push-button of a tape recorder to which the brushless *dc* motor M is applied, to operate the slide switches SW_1 and SW_2 automatically.

Next, the operation of the circuit of Figure 17 will be described. For example, when the reproducing push-button of the tape recorder is depressed, the knobs 40 and 41 of the slide switches SW_1 and SW_2 are actuated by interlocking members such as levers (not shown). The movable contacts of the motor starting/stopping switches S_7, S_8 and S_9 are connected to the first stationary contacts a_1, a_2 and a_3, and at the same time, the movable contacts of the series-parallel change-over switches S_1 to S_6 are connected to the first stationary contacts c_1, f_1, c_2, f_2, c_3 and f_3. Thus, the coil unit 22*a* is connected in series with the coil unit 22*b*, the coil unit 21*b* is connected in series with the coil unit 21*a*, and the coil unit 20*a* is connected in series with the coil unit 20*b*. The coil units are connected to the transistors Q_1, Q_2 and Q_3. As above described, the transistors Q_1, Q_2 and Q_3 as the first, second

and third switching elements are turned on and off in order with the detecting outputs of the Hall elements 31a to 31c of the detecting plate 30. Current Ic flows through the series-connected coil units 22a and 22b, 21b and 21a, and 20a and 20b, in order. The rotational speed of the rotor assembly 15 is detected with the change of the capacitance between the teeth 8a of the positioning ring 8 and the teeth 38 of the stator-side speed detecting ring head 37. The detecting output from the stator-side speed detecting ring heads 37 is applied to the control circuit 50. The output of the latter is supplied to the base of the transistor Q_4. The current Ic, namely the rotational speed of the motor M is so controlled as to be constant, by the control transistor Q_4. Thus, the motor M is rotated at the constant speed for the reproduction.

Next, when the stop push-button of the tape recorder is depressed, the knob 40 of the slide switch SW_1 is not actuated, but the knob 41 of the other slide switch SW_2 is actuated into another position. The movable contacts of the motor starting/stopping switches S_7, S_8 and S_9 are changed over to the second stationary contacts b_1, b_2 and b_3. Accordingly, the series-connected coil units 22a and 22b, 21a and 21b, and 20a and 20b are disconnected from the transistors Q_1, Q_2 and Q_3, namely from the battery E_0. However a closed loop is formed in each of the series-connected coil units 22a and 22b, 21a and 21b, and 20a and 20b. A counter-electromotive force is induced in each of the coil units to brake the rotor assembly 15. The latter stops instantly.

Next, when the fast-forwarding push-button or the rewind push-button of the tape recorder is depressed, the knobs 41 and 40 of the slide switches SW_2 and SW_1 are actuated with the interlocking mechanism (not shown). The movable contacts of the motor starting/stopping switches S_7, S_8 and S_9 are connected to the first stationary contacts a_1, a_2 and a_3, while the movable contacts of the series-parallel change-over switches S_1 to S_6 are connected to the second stationary contacts d_1, e_1, d_2, e_2, e_3. With the change-over of the switches S_1 to S_6, the coil unit 22a is connected in parallel with the coil unit 22b, the coil unit 21a is connected in parallel with the coil unit 21b, and the coil unit 20a is connected in parallel with the coil unit 20b. The parallel-connected coil units 22a and 22b, 21a and 21b, and 20a and 20b are connected to the transistors Q_1, Q_2 and Q_3. In the above-described manner, the transistors Q_1, Q_2 and Q_3 are turned on and off in order with the detecting outputs of the Hall-elements 31a, 31b and 31c of the detecting plate 30 to pass a current I_D through the parallel-connected coil units 22a and 22b, 21a and 21b, and 20a and 20b, respectively. As a result, the rotor assembly 15 is rotated at the higher speed for the fast-forward mode or the rewind mode. In this case, the speed of the rotor assembly 15 may be controlled with the control transistor Q_4 supplied with a higher level control signal. Alternatively, the emitter and collect r of the transistor Q_4 may be short-circuited with each other. In ths case, the speed of the rotor assembly 15 is not controlled.

Next, the advantage of the drive circuit of Figure 17 will be described with reference to Figure 19 to Figure 22.

Generally, tape recorders are divided into one-motor type, two-motor type and three-motor type from the viewpoint of the number of the drive motors for tape running. In the tape recorder of the three-motor type, two motors are used for driving two reel shafts to supply and take-up a magnetic tape, and one motor is used for driving a capstan. In this type, the shafts of the motors may be directly connected to the respective reel shafts. Alternatively, mechanical transmission mechanism may be arranged between the motor shafts and the reel shafts. In the tape recorder of the two-motor type, one common motor is used for driving two reel shafts to supply and take-up a magnetic tape, and one motor is used for driving a capstan. A mechanical transmission mechanism is arranged between the reel shafts and the shaft of the common motor. The shaft of the motor functions as the capstan. Finally in the tape recorder of the one-motor type, one motor is used for driving the two reel shafts and the capstan. The one-motor type is widely employed for a portable tape recorder. In this type, the one motor is combined with different mechanical transmission mechanism so as to transmit the rotational forces to the reel shafts and capstan.

For comparison with the embodiment of this invention, the drive circuit of the conventional one-motor type is shown in Figure 19 and Figure 20. Next, operation of the drive circuit of Figure 19 will be described to understand the advantage of the drive circuit of Figure 17 according to the embodiment of this invention. Parts in Figure 19 which correspond to the parts in Figure 17, are denoted by the same reference numerals or letters.

In Figure 19, three coil units L_1, L_2 and L_3 are connected in series with the transistors Q_1, Q_2 and Q_3, respectively. The transistors Q_1, Q_2 and Q_3 are turned on and off in order with the detecting outputs of the position detecting elements, applied to the bases of the transistors Q_1, Q_2 and Q_3. In the play mode of the tape recorder, a control signal of a predetermined level is supplied to the base of the control transistor Q_4 from the control circuit 50, and a current I_A flows through the coil units L_1, L_2 and L_3 in order. The voltage drops across the transistors Q_1, Q_2 and Q_3 are nearly zero. Accordingly, the circuit of Figure 19 can be expressed as the circuit of Figure 20. When the current I_A flows thr ugh the control transistor Q_4, the voltage drop across the transistor

Q_4, as a control loss, amounts to E_1. Accordingly, the terminal voltage E_2 of the conventional motor M' is expressed by the following equation:

$$E_2 = E_0 - E_1.$$

With the control loss by the control transistor Q_4, the motor M' is rotated at the low speed for the play mode.

When the tape recorder is changed over into the fast-forward mode or the rewind mode, a control signal of a higher level is supplied to the base of the control transistor Q_4, or the emitter and collector of the control transistor Q_4 are short-circuited with each other. A current I_B flows through the motor M'. The voltage drop E_1 across the control transistor Q_4 is nearly zero. Accordingly, the terminal voltage E_2 of the motor M' is nearly equal to the voltage E_0 of the power source. The motor M' is rotated at the high speed for the fast-forward mode or rewind mode.

Figure 21 shows the output characteristics of the above-described motor M'. In Figure 21, an abssissa represents the torque T of the motor M', a first ordinate Y_1 represents the rotational speed N of the motor M', and a second ordinate Y_2 represents the current I flowing through the motor M'. In the graphs of Figure 21, a curve I_0 shows the relationship between the torque T of the motor M' and the load current flowing through the motor M'. A curve A_1 shows the relationship between the torque of the motor M' and the rotational speed of the motor M' when the terminal voltage of the motor M' is nearly equal to E_0. And a curve A_2 shows the relationship between the torque of the motor M' and the rotational speed of the motor M' when the rotational speed of the motor M' is controlled to the constant speed N_2.

When the maximum torque required to run the tape at the low speed N_2 is T_2, the current flowing through the motor M' amounts to I_a. And when the torque required to run the tape at the high speed N_1 is T_1, the current flowing through the motor M' amounts to I_B. If the speed of the motor M' is not controlled in the fast-forward mode or rewind mode, it varies with the torque of the motor M'. In this case, the rotational speed N_1 is considered to represent the mean value.

Table I shows the motor inputs and the control losses in the play mode or record mode and the fast-forward mode or rewind mode, for the conventional m tor M'.

Generally, it is required for the tape recorder that the motor is rotated at the desired high speed within the range of the guaranteed voltage of the battery. When the motor is larger-sized and the speed of the motor is controlled to N_1, the control loss in the play or record mode increases.

In some of the tape recorders, a speed-increasing mechanism with the motor is arranged to obtain the desired high speed. However, such a tape recorder is complicated in construction.

Figure 22 shows the output characteristics of the motor M according to the embodiment of this invention. In Figure 22, an abscissa represents the torque T of the motor, a first ordinate Y_1 represents the rotational speed N of the motor, a second ordinate Y_2 represents the current flowing through the motor where the coil units 22*a* and 22*b*, 21*a* and 21*b*, and 20*a* and 20*b* are in parallel with each other, respectively, and a third ordinate Y_3 represent the current flowing through the motor where the coil units 22*a* and 22*b*, 21*a* and 21*b*, and 20*a* and 20*b* are in series with each other, respectively. The current flowing through the parallel-connected coil units is about four times as high as the current flowing through the series-connected coil units. In the graphs of Figure 22, a curve I_P shows the relationship between the torque T of the motor and the load current flowing through the motor where the paired coil units are connected in parallel with each other. A curve A_4 shows the relationship between the torque T of the motor and roaational speed of the motor where the terminal voltage of the motor is nearly equal to E_0 and the paired coil units are connected in parallel with each other. A curve I_0 shows the relationship between the torque T of the motor and the current flowing through the motor where the paired coil units are connected in series with each other. And a curve A_3 shows the relationship between the torque T of the motor and the rotational speed of the motor when the paired coil units are connected in series with each other, and the rotational speed of the motor is controlled to the constant speed N_2. The rotational speed N_3 is substantially equal to the rotational speed N_1

TABLE I

Motor input in play or record mode	$E_2 I_A$
Control loss in play or record mode	$(E_0 - E_2) I_A$
Motor input in fast-forward or rewin mode	$E_0 I_B$
Control loss in fast-forward or rewind mode	Negligibly small

TABLE II

Motor input in play or record mode	$E'_2 I_C$
Control loss in play or record mode	$(E_0 - E'_2) I_C$
Motor input in fast-forward or rewind mode	$E_0 I_D$
Control loss in fast forward or rewind mode	Negligibly small

of the above-described conventional motor M'. When the terminal voltage of the motor in the play or record mode is expressed by E_2', the following Table II is obtained from the graphs of Figure 22.

Next, the power loss of the drive circuit of the conventional motor M' of Figure 19 will be compared with that of the drive circuit of the motor M of Figure 17 according to the embodiment of this invention, with reference to Tables I and II.

In the play mode or record mode,

$E_2 I_A = E_2' I_C'$ and $E_2' \gg E_2'$

therefore, $I_A \gg I_C$ and $E_0 - E_2 > E_0 - E_2'$. Accordingly, the relationship between the control losses, namely the power losses by the control trasistors Q_4, is expressed by the following equation.

$$(E_0 - E_2) I_A \gg (E_0 - E_2') I_C:$$

From the above equation, it will be understood that the control loss in the motor according to this embodiment is mush smaller than that in the conventional motor, in the play mode or record mode.

In the fast-forward or rewind mode, the iron loss in the magnetic circuit of the conventional motor M' is substantially the same as the iron loss in the magnetic circuit of the motor M according to the embodiment, if the construction of the motor M' is the same as that of the motor M. However, the paired coil units are connected in parallel with each other in the motor M according to this embodiment. Accordingly, copper loss of the motor M is smaller than that of the conventional motor M'. Therefore, the motor input in the fast-forward mode or rewind mode can be substantially reduced in comparison with the conventional motor M'.

Figure 23 shows one example of a rotational force transmission mechanism of a capstan direct-drive type tape recorder to which the motor according to this embodiment of the invention is applied.

The reverse mode is possible according to this tape recorder. An output roller 60 is fixed to the capstan shaft 14. A magnetic tape 52 is pinched between the capstan 14 and a pinch roller 51 to be run thereby. A swingable transmission idler 53 contacts with the output roller 60. The position of the swingable idler 53 can be changed over with a transmission mechanism (not shown) interlocked with the push-buttons of the tape recorder. In the play mode, record mode and fast-forward mode, the idler 53 is interposed between the output roller 60 and a take-up reel mount 54*b*, as shown by the solid line in Figure 23, to rotate the take-up reel mount 54*b* in the X-direction.

In the rewind mode and the reverse mode, the idler 53 is interposed between the output roller 60 and a supply reel mount 54*a*, as shown by the dot-dash line in Figure 23, to rotate the supply reel mount 54*a* in the Z-direction. In this case, the motor M is rotated in the reverse direction with depression of the associated push button.

The magnetic tape 52 is transported wire predetermined tension between tape guide pins 55*a* and 55*b*; in the right or left direction. A recording/reproducing magnetic head 56 and erasing magnetic head 57 for the normal play mode and record mode are arranged between the capstan shaft 14 and the tape guide pin 55*a*. Another recording/reproducing magnetic head 58 and erasing magnetic head 59 for the reverse mode are arranged between the capstan shaft 14 and the tape guide pin 55*b*.

The capstan shaft 14, namely the output roller 60 is rotated at the lower speed in the play mode or record mode, in the X-direction. And it is rotated at the higher speed in the fast-forward mode, in the X-direction.

The cppstan shaft, 14 namely the output roller 60 is rotated at the lower speed in the reverse mode, in the Z-direction. And it is rotated at the higher speed in the rewind mode, in the Z-direction.

The above-described flat brushless *dc* motor according to one embodiment of this invention has the following merits.

(a). The assembling operation is very simple.

The construction can be ideally flattened. The rotary shaft 14 can be stably supported by the bearings 5 and 6, and moreover can be accurately supported thereby with respect to the concentricity of the construction.

(*b*. Since the rotary cylindrical member 11 combining the upper rotary ring 13 and the lower rotary ring 9 with each other is made of non-magnetic material such as brass, the magnetic flux from the parmanent magnet 7 is not shunted to the rotary cylindrical member 11, it flows effectively only between the upper and lower rotary rings 13 and 9 substantially in parallel with the rotary shaft 14. Magnetomotive force of the magnet 7 can be effectively used for generation of rotational force.

(*c*). Since the upper and lower rotary rings 13 and 9 between which magnetic attractive force is generated, are combined with each other vy the rotary cylindrical member 11, little bending force is applied to the rotary shaft 14 fixed to the centre of the bottom of the rotary cylindrical member 11, and so the rotary shaft 14 can be very stably supported by the bearings 5 and 6 fixed on the inner surface of the stationary cylindrical member 4.

(*d*). Since the distance between the bearings supporting the rotary shaft 14, and the working point of the rotary shaft 14 at which the pinch roller 51 is pressed to the rotary shaft 14 as the capstan to pinch the magnetic tape therebetween, can be so

designed as to be the shortest possible, the bending moment to the rotary shaft 14 can be the smallest possible.

(*e*). The leakage magnetic flux from the permanent magnet 7 is sensed by the detecting elements of the detecting plate 30 to detect the rotational position of the rotor assembly 15. No special magnetic marker for detecting the rotational position is required. The detecting plate 30 can be easily assembled into the motor. For that purpose, a narrow space in the flat brushless motor can be effectively used. Since the position of the detecting plate 30 can be adjusted in the peripheral direction while the rotor assembly 15 is rotated, the error of the arrangement between the coil units and the position-detecting elements attached to the detecting plate 30 can be compensated, and so the motor can be driven at the optimum condition.

(*f*). The coil units can be very stably arranged in the coil assembly. The whole thickness of the coil assembly can be the smallest possible. Since the coil units are partially fixed to each other, the coil assembly is stable in construction. Moreover, the coil units can be accurately and stably positioned by the positioning ring 24. Various modifications can of course be made. For example, although the stationary cylindrical member 4 having the bearings 5 and 6 is fixed to the upper casing 1 in the above embodiment, it may be fixed to a part of a chassis in a tape recorder. Figure 24 shows one example of such a modification in which some parts are omitted. Parts in this modification which correspond to the parts in the above embodiment are denoted by the same reference numerals, and will not be described hereinafter in detail.

In Figure 24, the stationary cylindrical member 4 is fixed to an opening 72*a* of a chassis 72 made of iron. The magnets 7 are fixed to an upper dish-like rotary ring 70, and positioned in the manner different from the above embodiment. Teeth 70*a* are made in the outer circumferential surface of the upper rotary ring 70. A stepped support ring member 73 of synthetic resin is united with the iron chassis 72. The former and latter can be molded as one body by the so-called "outsert method". The stepped support ring member 73 has first, second and third support portions 73*a*, 73*b* and 73*c*. The coil assembly 12 of Figure 12 is fixed to the first support portion 73*a* by screws. The detecting plate 30 is fixed to the coil assembly 12 by screws after the angular position of the detecting plate 30 relative to the coil assembly 12 is adjusted as guided by a circular cut-out recess 73*a*, of the first support portion 73*a*. A thrust bearing plate 78 is fixed to the third support portion 73*c* by screws, amd supports the lower end of the capstan shaft 14. A stator-side speed detecting ring head 77 is fixed to the inner circumferential surface of the stepped support ring member 73. Teeth 77*a* made on the inner circumferential surface of the stator-side detecting ring head 77 face the teeth 70*a* of the upper dish-like rotary ring 70. A head terminal 78 fixed to the second support portion 73*b* is electrically connected to the stator-side speed detecting ring head 77. Well-known parts for the tape recorder are mounted on the chassis 72. For example, cassette-positioning pins 80 and 81, and a pinch roller arm 82 are mounted on the chassis 72. The pinch roller 51 is rotatably supported by the pinch roller arm 82. The magnetic tape (not shown) is pinched between the pinch roller 51 and the capstan shaft 14.

Since the chassis 72 is made of iron, the parts above the chassis 72 are electro-magnetically shielded from the motor M. According to thos modification, the tape recorder can be formed to super-flat configuration, since the upper and lower casings are omitted.

Figure 25 and Figure 26 show one modification of the coil assembly 12 of Figure 12. Parts in this modification which correspond to the parts in Figure 12 and Figure 13 are denoted by the same reference numerals, and will not be described hereinafter in detail.

The coil assembly 12′ of this modification has the six coil units 20*a*, 20*b*, 21*a*, 21*b*, 22*a* and 22*b*, two similar coil mounting rings 90 and 91, and the printed plate 23. The three coil units 20*a*, 21*a* and 22*a* are fixed at angularly regular intervals of 120 degrees to the inner circumferential surface of the one coil mounting ring 90 by adhesive. And the other three coil units 20*b*, 21*b* and 22*b* are fixed at angularly regular intervals of 120 degrees to the inner circumferential surface of the other coil-mounting ring 91 by adhesive. The thickness of the coil-mounting rings 90 and 91 is slightly larger than that of the coil units 20*a* to 22*b*. The diameter of the central openings 90*a* and 91*a* is smaller than that of the central opening 23*d* of the printed plate 23.

The coil-mounting rings 90 and 91 are put on each other in such a manner that the six coil units are arranged at angularly regular intervals of 60 degrees, and the central openings 90*a* and 91*a* are aligned with each other. The coil units are fixed to each other at their overlapping portions by adhesive. And the two coil-mounting rings 90 and 91 fixed to each other are fixed to the printed plate 23 so that the central opening 90*a* and 91*a* are concentrical with the central opening 23*d* of the printed plate 23. In this modification, the necessary circuits are printed on the lower surface of the printed plate 23. In a similar manner to the above embodiment, the terminal ends of the coil units are soldered to the circuits on the printed plate 23. The coil assembly 12′ thus obtained is fixed t the upper casing 1 by means of the screw holes

23b. As a result, a rotor-stator assembly 92 corresponding to the rotor-stator assembly 29 of Figure 14 is obtained as shown in Figure 27.

According to this modification, the number of the coil units can be easily varied in accordance with the requirements of the motor, by piling the coil-mounting rings. That is an advantage in parts control.

Figure 28 to Figure 32 show another modification of the coil assembly 12 of Fugure 12. Parts in this modification which correspond to the parts in Figure 12, are denoted by the same reference numerals.

Referring to Figure 28, a first coil-mounting plate 95 is made of flexible material, for example, 110μ thick such as epoxy resin containing glass fibre. Necessary circuits (partially shown) are printed on the first coil-mounting plate 95. The coil-mounting plate 95 comprises a ring portion 95a, a projecting terminal portion 95b, and three lead-connecting portions 97a, 97b and 97c projecting radially inward from the inner circumferential edge 96 of the ring portion 95a at angularly regular intervals of 120 degrees.

Referring to Figure 29, a second coil-mounting plate 98 is made of the same material as the first coil-mounting plate 95. Necessary circuits are printed on the back surface of the plate 98. Similarly to the first coil-mounting plate 95, the second coil-mounting plate 98 comprises a ring portion 98a, a projecting terminal portion 98b and three lead-connecting portions 94a, 94b and 94c projected from the inner circumferential edge 99 of the ring portion 98a at angularly regular intervals of 120 degrees. However, the lead-connecting portions 97a, 97b and 97c are shifted from the lead-connecting portions 94a, 94b and 94c when the projecting terminal portion 95b of the first coil-mounting plate 95 is aligned with the projecting terminal portion 98b of the second coil-mounting plate 98.

Next, the coil units 20a, 21a and 22a are arranged on the back surfaces of the lead-connecting portions 97a, 97b and 97c of the coil-mounting plate 95 so that the central lines of the coil units 20a, 21a and 22a are aligned with the central lines of the lead-connecting portions 97a, 97b and 97c, and the outer arcuate edges of the coil units 20a, 21a and 22a are aligned with the inner edge 96 of the ring portion 95a of the coil-mounting plate 95. The coil units 20a, 21a and 22a may be fixed to the lead-connecting portions 97a, 97b and 97c by adhesive.

Similarly, the coil units 20b, 21b and 22b are arranged on the front surfaces of the lead-connecting portions 94a, 94b and 94c, and they may be fixed to the latter by adhesive.

The initial ends ℓ and the terminal ends m of the coil units 20a and 21b are soldered to the printed circuits on the lead-connecting portions 97a, 97b, 97c, 94a, 94b and 94c at the nearest points, respectively, in the manner shown in Figure 28 and Figure 31. Insulating films are deposited on the printed circuits of the first and second coil-mounting plates 95 and 98.

Next, the second, coil-mounting plate 98 with the coil units is superimposed on the first coil-mounting plate 95 with the coil units in the manner shown by the Figure 30A and Figure 30B. The projecting terminal portions 95b and 98b are put together on each other. The lead-connecting portions 97a, 97b, 97c, 94a, 94b and 94c are interposed between the adjacent coil units in the superimposed coil-mounting plates 95 and 98 as shown in Figure 31. The lead-connecting portions 97a, 97b and 97c of the first (lower) coil-mounting plate 95 are bent upwardly at the base ends as shown in Figure 32, while the lead-connecting portions 94a, 94b and 94c of the second (upper) coil-mounting plate 98 are bent downwardly at the base ends as shown in Figure 32. A permissible smallest bending radius is 5ψ for epoxy resin containing glass fibre material and being 110μ thick. Accordingly, the lead-connecting portions 94a to 97c can be easily bent in the manner shown in Figure 32. The coil units are fixed to each other at the overlapping portions by adhesive. The coil-mounting plates 95 and 98 afe fixed to each other by adhesive. Alternatively, the whole of the coil assembly obtained may be hardened with suitable resin.

Figure 33 shows a further modification of the coil assembly shown in Figure 28 to Figure 32. In this case, the six coil units 20a to 22b are first equally divided into the upper and lower groups, and arranged at angularly regular intervals of 60 degrees in the manner shown in Figure 33. They are fixed to each other by adhesive. Then, the first and second coil-mounting plates 95 and 98 are combined with the thus obtained coil-unit assembly C so that the lead-connecting portions 97a, 97b, 97c, 94a, 94b and 94c are interposed between the adjacent coil units. The outer circumferential surface of the coil-unit assembly C is fixed to the inner edge 96 and 99 of the supcrimposed coil-mounting plates 95 and 98 by adhesive. The initial ends ℓ and terminal ends m of the coil units are soldered to the lead-connecting portions 94a, 94b, 94c, 97a, 97b and 97c at the nearest position, although they are not shown in Figure 33. In the case of Figure 33, the lead-connecting portions 94a, 94b, 94c, 97a, 97b and 97c are not bent at the base ends.

Figure 34 and Figure 35 show a still further modification of the coil assembly shown in Figure 28 to Figure 32. In this modification, the first and second coil-mounting plates 95 and 98 are united with each other.

In Figure 34, a coil-mounting plate 150

comprises first and second coil-mounting parts 130 and 140, and they correspond to the above-described first and second coil-mounting plates 95 and 98. Similarly, lead-connecting portions 131*a*, 131*b*, 131*c*, 141*a*, 141*b* and 141*c* correspond to the above-described lead-connecting portions 97*a*, 97*b*, 97*c*, 94*a*, 94*b* and 94*c*. The first and second coil-mounting parts 130 and 140 are connected to each other by a common terminal portion 135. Necessary circuits (partically shown) are printed on the surface of the coil-mounting plate 150. Although the circuits of the first coil-mounting plate 95 are not originally connected to the circuits of the second coil-mounting plate 98 in the coil assembly of Figure 28 to Figure 32, the circuits to be connected are originally connected in the modification of Figure 34 and Figure 35, as shown by circuits 136 and 137, Accordingly, the sequential wiring operation is reduced.

In the coil mounting step, the coil-mounting plate 150 is bent at the central portion of the common terminal portion 135 as shown in Figure 35. The printed circuits face to the exterior. The coil-unit assembly C shown in Figure 33 is interposed between the first and second coil-mounting parts 130 and 140. Ring portions 130*a* and 140*a* of the first and second coil-mounting parts 130 and 140 are fixed to each other by adhesive . The outer circumferential surface of the coil-unit assembly C is fixed to the inner edges of the coil-mounting plate 150 by adhesive. The initial ends ℓ and terminal ends *m* of the coil units are soldered to the printed circuits of the lead-connecting portions 131*a*, 131*b*, 131*c*, 141*a*, 141*b*, and 141*c*, at the nearest positions.

In the modifications of the coil assembly of Figure 28 to Figure 35, the initial ends ℓ and terminal ends *m* of the coil units can be easily connected to the circuits, and it can be avoided that the wires of the coil units extend across the coil unit or coil units.

Figure 36 shows one modification of the drive circuit of Figure 17. Parts in Figure 36 which correspond to the parts in Figure 17, are denoted by the same reference numerals, and will not be described in detail. In this modification, three coil units L_{10}, L_{20} and L_{30} are arranged in the coil assembly. Centre taps are fixed to the coil units L_{10}, L_{20} and L_{30} at predtermined positions, and they are connected to second stationary contacts *b* of change-over switches S_{10}, S_{20} and S_{30}, respectively. First stationary contacts *a* of the switches S_{10}, S_{20} and S_{30} are connected to terminal ends of the coil units L_{10}, L_{20} and L_{30}. Movable contacts *c* of the switches S_{10}, S_{20} and S_{30} are connected to the collectors of the transistors Q_1, Q_2 and Q_3. The movable contacts *c* of the switches S_{10}, S_{20} and S_{30} are ganged with each other.

When the movable contacts *c* of the swtiches S_{10}, S_{20} and S_{30} are connected to the stationary contacts *a* the impedances of the coil units L_{10}, L_{20} and L_{30} are higher, and the motor M is rotated at the lower speed. An when the movable contacts *c* of the switches S_{10}, S_{20} and S_{30} are connected to the second stationary contacts *b*, the impedances of the coil units L_{10}, L_{20} and L_{30} are reduced, and the motor M is rotated at the higher speed. Also this modification has the same advantage as the above-described drive circuit of Figure 17.

WHAT WE CLAIM IS:

1. A brushless direct current motor comprising: a stator member; a stationary cylindrical member mounted on said stator member and having bearings on its inner circumferential surface; a rotary shaft rotatably supported by said bearings of said stationary cylindrical member; a rotary cylindrical member into which said stationary cylindrical member projects, and to which said rotary shaft is fixed; at least two rotary discs of magnetic material, fixed to said rotary cylindrical member and spaced from each other; at least one permanent magnet fixed to one of said rotary discs; a rotational-position detecting member arranged on said stator member to detect the angular position of said rotary discs; and a coil assembly arranged on said stator member, including a plurality of coil units arranged to be selectively energized in response to the output of said rotational-position detecting member; the arrangement of said rotary shaft being such that in use of the motor the drive said rotary shaft is derived from that end of said rotary shaft which is nearer to said station cylindircal member than to said rotary cylindrical member.

2. A motor according to claim 1 wherein said rotary cylindrical member is made of non-magnetic material.

3. A motor according to claim 2 wherein said non-magnetic material is brass.

4. A motor according to claim 1, claim 2 or claim 3 wherein said bearings are made of oleo sintered alloy.

5. A motor according to claim 1 wherein said coil assembly includes an even number of flat coil units, said coil units are equally divided into two groups and arranged on a circle without overlapping on each other in said respective groups, and each of said flat coil units of one of said two groups is overlapped by adjacent ones of said flat coil units of the other of said two groups, said flat coil units of one of said two groups being fixed to said flat coil units of the other of said two groups.

6. A motor according to claim 1 wherein said coil assembly includes a coil units mounting plate having a circular recess, said coil units being positioned by said circular recess.

7. A motor according to claim 6 wherein said coil unit mounting plate comprises two mounting members having circular openings of different diameters, and said mounting

members are superposed on each other so that said circular openings are concentric with each other, to form said circular recess.

8. A motor according to claim 1 wherein said coil assembly includes flat coil units and a plurality of coil unit mounting rings, said flat coil units are fixed at the outer arcuate surfaces to the inner circumferential surfaces of said plurality of coil unit mounting rings, said plurality of coil unit mounting rings are piled on each other, and said flat coil unit mounted on one of said coil unit mounting rings are fixed to said flat coil units mounted on another of said coil unit mounting rings at their overlapping portions.

9. A motor according to claim 1 wherein said coil assembly includes flat coil units and at least one coil unit mounting plate having an opening, band-like lead-connecting portions extending in said opening are formed in said coil unit mounting plate, and at least the initial ends of wires of said coil units are connected to said lead-connecting portions.

10. A motor according to claim 10 wherein said coil unit mounting plate is made of flexible material.

11. A motor according to claim 10 wherein said coil unit mounting plate comprising two coil unit mounting parts combined with each other, said coil units being interposed between said two coil units mounting parts.

12. A motor according to claim 1 wherein said rotational-position detecting member comprises an arcuate plate provided with rotational-position detecting elements, said arcuate plate being radially positioned by a part of said stator member and being capable of being adjusted in the peripheral direction.

13. A motor according to claim 12 wherein said arcuate plate includes a protrusion accessible from the exterior of the motor.

14. A motor according to claim 1 wherein the connections of said coil units can be changed over to change the output characteristic of the motor.

15. A motor according to claim 1 wherein said coil units are divided into a plurality of groups arranged to be energized in order with the detection outputs of said rotational-position detecting member, and said coil units of said respective groups are selectively changed over to parallel connections or series connections to change the impedances of said respective groups in accordance with the required output characteristic of said motor.

16. A motor according to claim 1 wherein each of said coil units includes at least one tap, and is arranged to be selectively energized through aaid tap or through the end terminals to change the impedance in accordance with the required output characteristic of the motor.

17. A motor according to any one of the preceding claims wherein said stator member forms part of the chassis of a magnetic tape recorder.

18. A brushless direct current motor substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

19. A brushless direct current motor substantially as hereinbefore described with reference to Figures 1 to 16B of the accompanying drawings.

20. A brushless direct current motor substantially as hereinbefore described with refernece to Figures 1 to 16B as modified by Figure 24 of the accompanying drawings.

21. A brushless direct current motor substantially as hereinbefore described with reference to Figures 1 to 16B as modified by Figures 25 to 27 of the accompanying drawings.

22. A brushless direct current motor substantially as hereinbefore described with reference to Figures 1 to 16B as modified by Figures 28 to 32 of the accompanying drawings.

23. A brushless direct current motor sub-substantially as hereinbefore described with reference to Figures 1 to 16B as modified by Figures 28 to 32 and 33 of the accompanying drawings.

24. A brushless direct current motor substantially as hereinbefore described with reference to Figures 1 to 16B as modified by Figures 28 to 32 and 34 and 35 of the accompanying drawings.

25. A brushless direct current motor substantially as hereinbefore described with reference to Figures 1 to 16B as modified by Figure 36 of the accompanying drawings.

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1576956 COMPLETE SPECIFICATION

28 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1

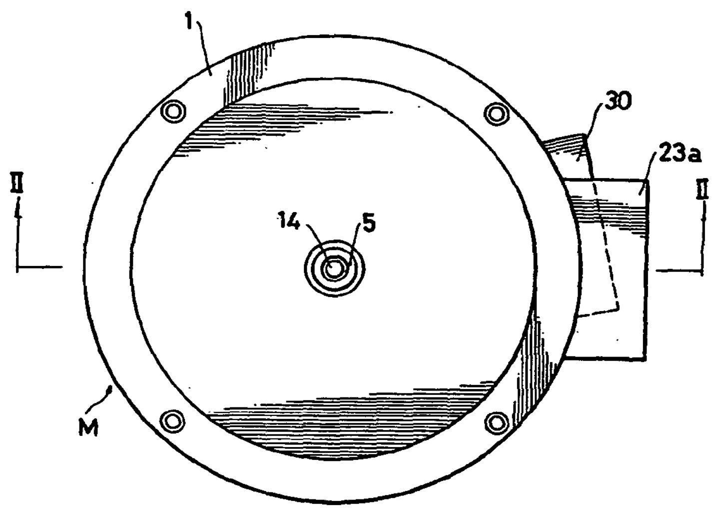


FIG.2

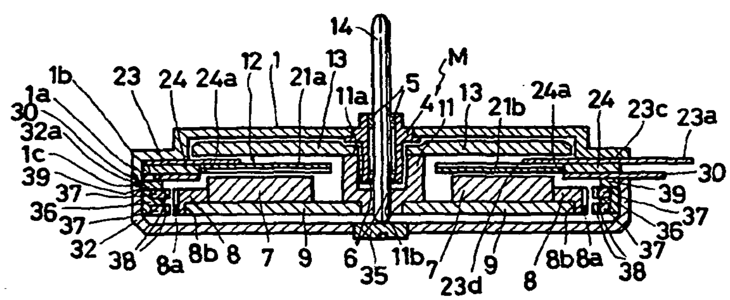


FIG.3A

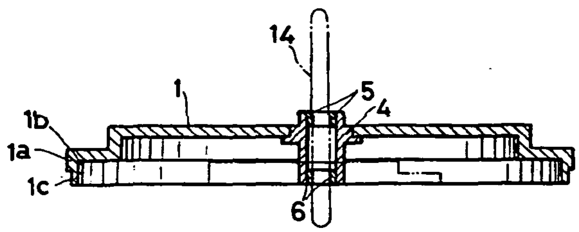


FIG.3B

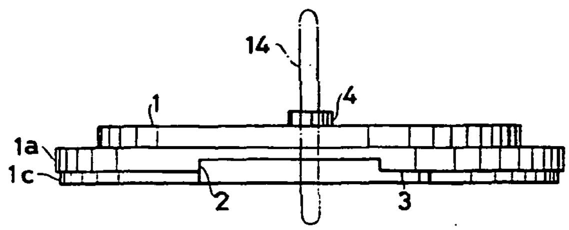


FIG.4

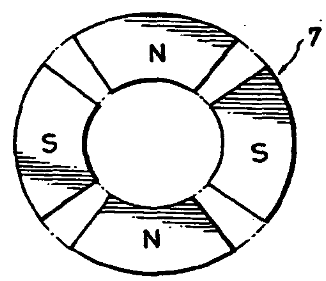


FIG.5

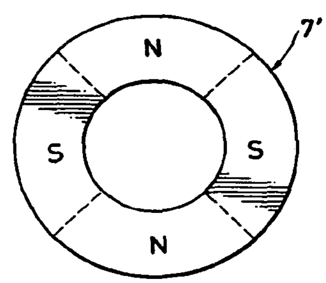


FIG.6A

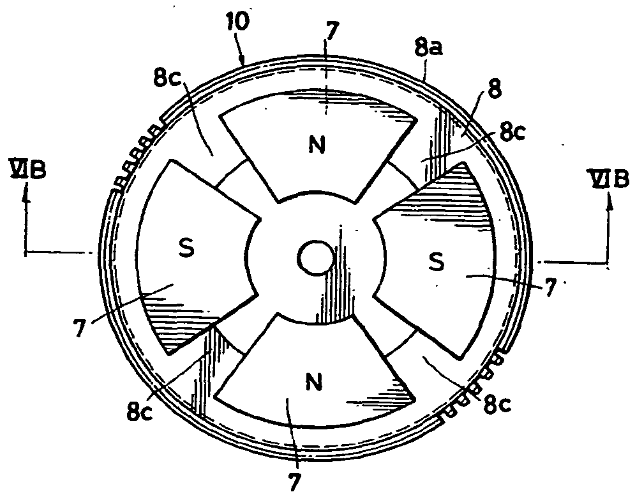


FIG.6B

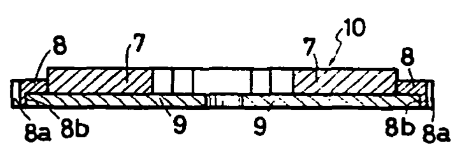


FIG.7

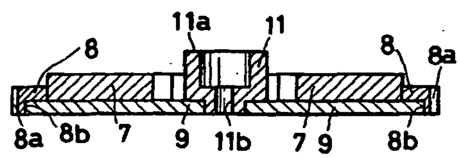

11a
11
8
8
8a
8a
8b
7
9
11b
7
9
8b

FIG.8

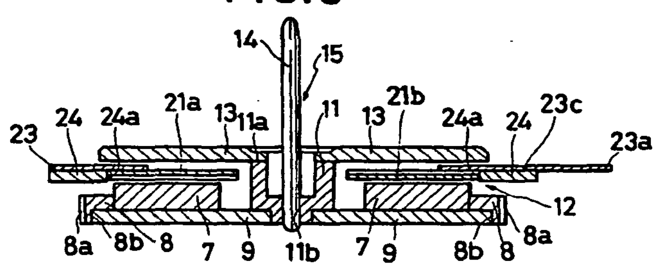

14
15
23
24
24a
21a
13
11a
11
13
21b
24a
24
23c
23a
12
8a
8b
8
7
9
11b
7
9
8b
8
8a

FIG.9

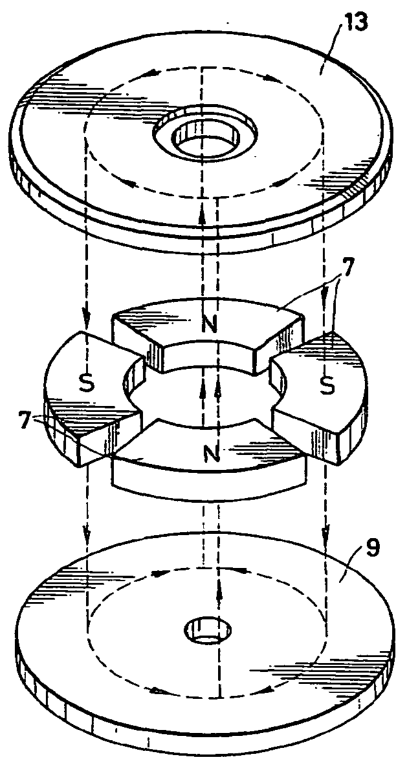


FIG.10

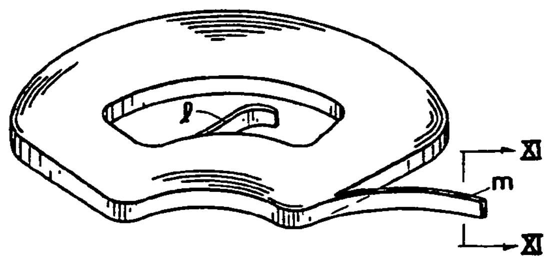


FIG.11

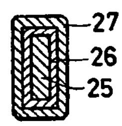


FIG.12

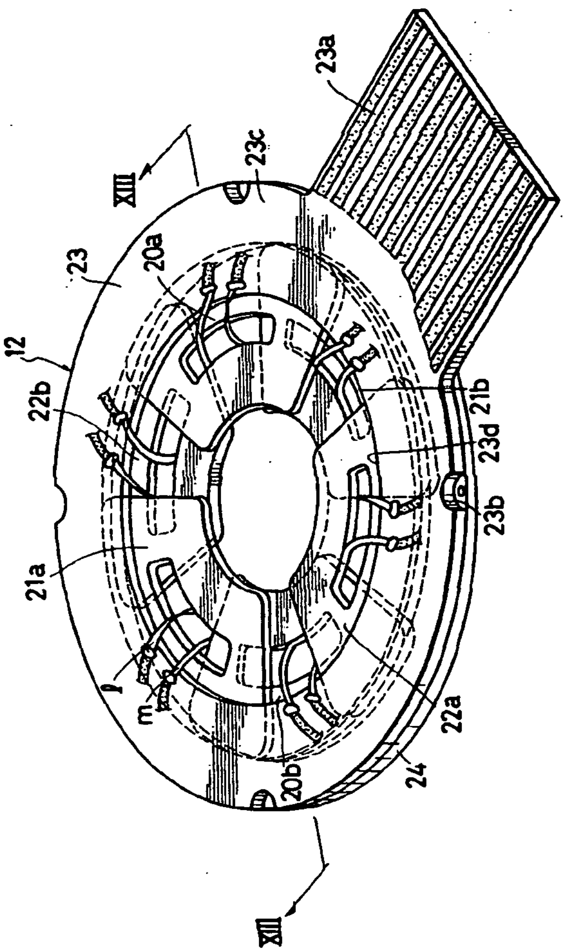


FIG.13

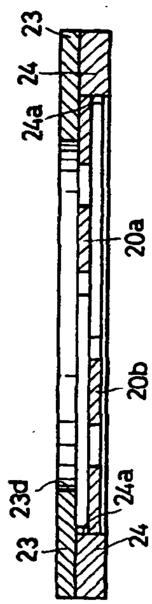


FIG.14

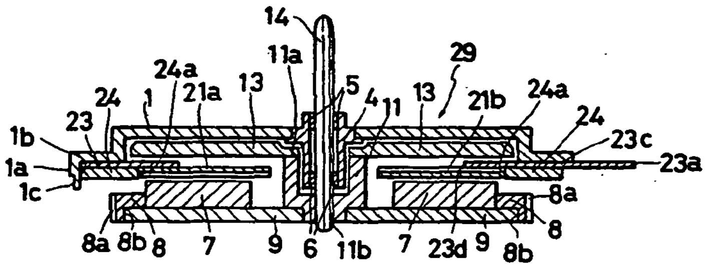

14
11a
29
24a
24
1
21a
13
5
4
11
13
21b
24a
24
23
23c
1b
1a
23a
1c
8a
8a
8b
8
7
9
6
11b
7
23d
9
8b
8

FIG.15

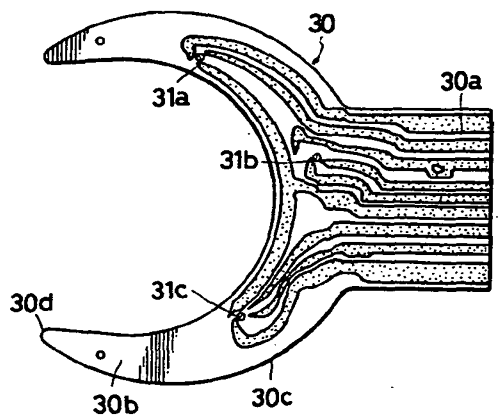

30
30a
31a
31b
31c
30d
30b
30c

FIG.16A

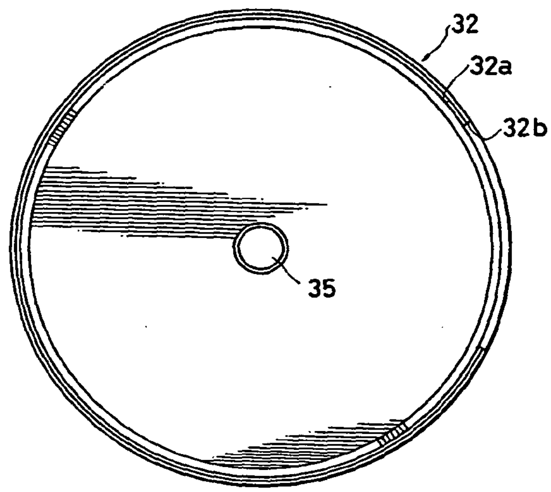


FIG.16B

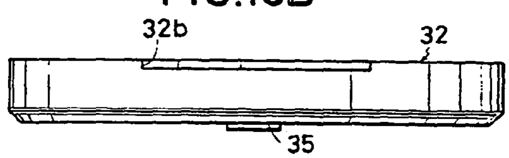
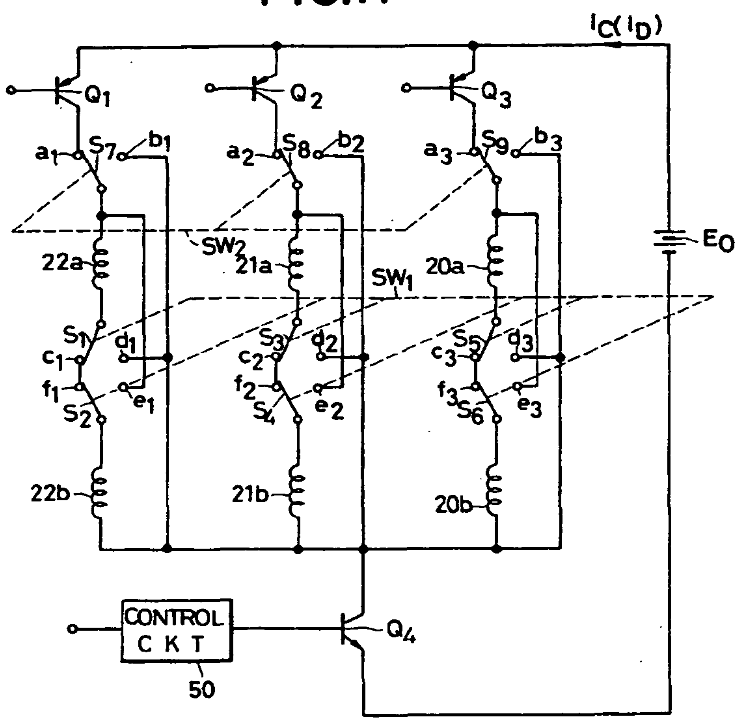


FIG.17


IC(ID)
Q1
Q2
Q3
a1
S7
b1
a2
S8
b2
a3
S9
b3
SW2
SW1
E0
22a
21a
20a
S1
d1
c1
f1
e1
S2
S3
d2
c2
f2
S4
e2
S5
d3
c3
f3
S6
e3
22b
21b
20b
CONTROL
CKT
50
Q4

1576956 COMPLETE SPECIFICATION

28 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 13

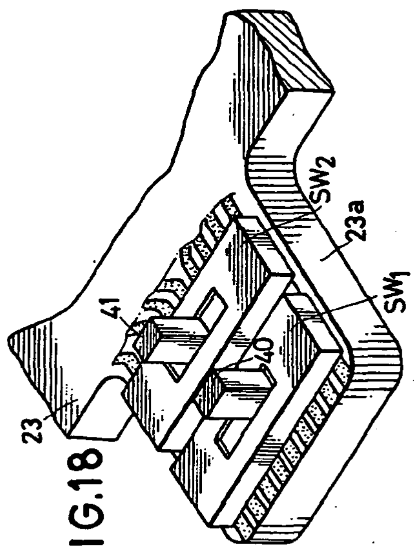


FIG.18

1576956 COMPLETE SPECIFICATION
28 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 14

FIG.20

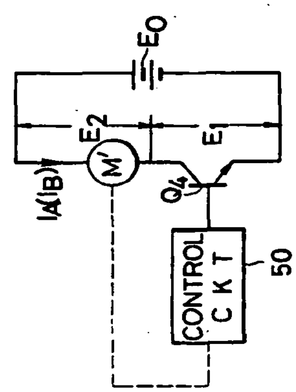


FIG.19

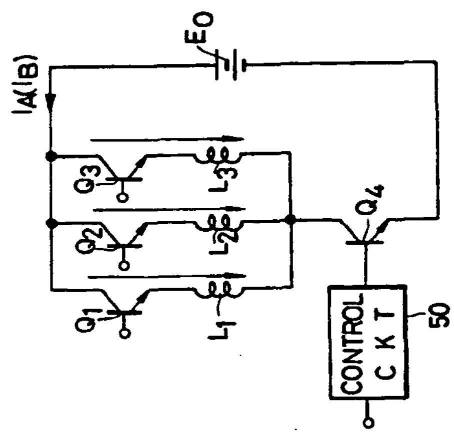


FIG.21

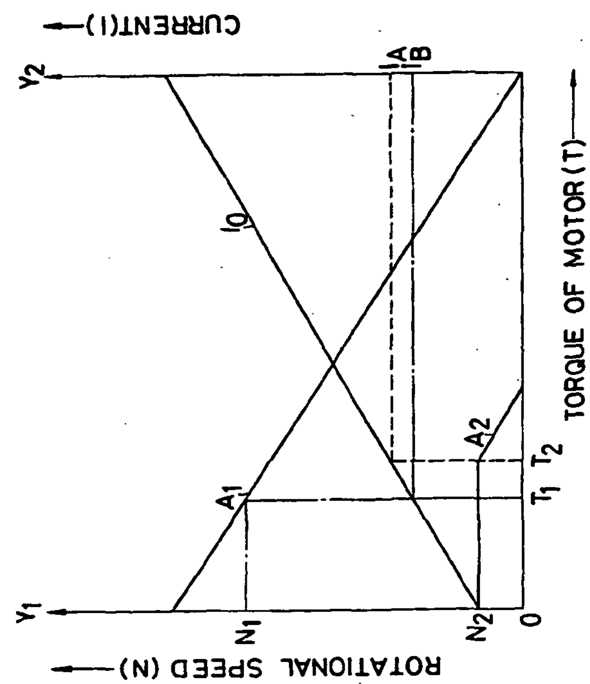

CURRENT(I)
ROTATIONAL SPEED (N)
TORQUE OF MOTOR (T)
Y1
Y2
IA
IB
I0
A1
A2
N1
N2
T1
T2
0

FIG. 22

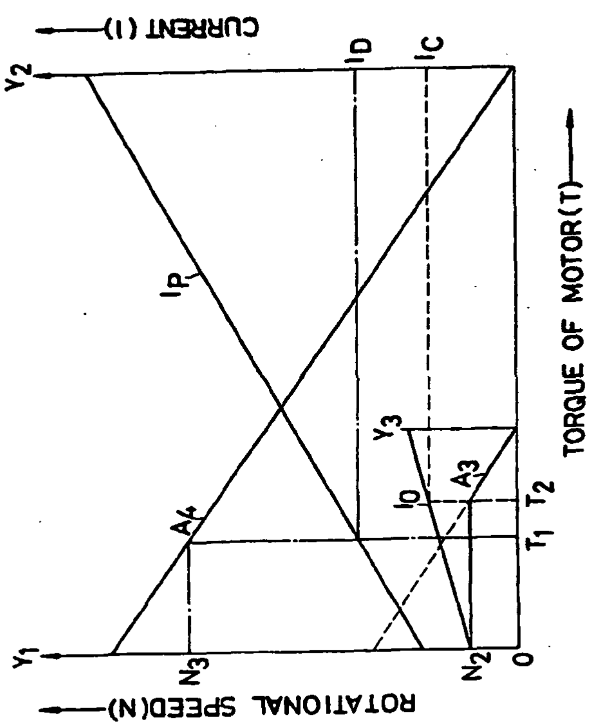

CURRENT (I)
ROTATIONAL SPEED(N)
TORQUE OF MOTOR(T)
Y_1
Y_2
Y_3
I_D
I_C
I_P
I_D
A_4
A_3
N_3
N_2
T_1
T_2
0

FIG. 23

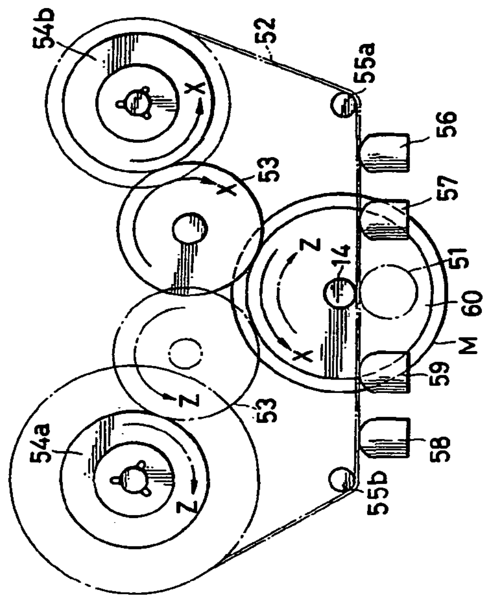


FIG.24

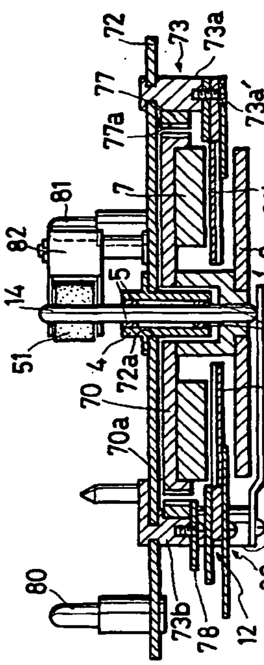

72
73
73a
77
77a
73a'
81
7
21b
82
9
5
M
14
6
51
4
72a
70
21a
70a
78
73c
30
80
73b
78
12

FIG. 25

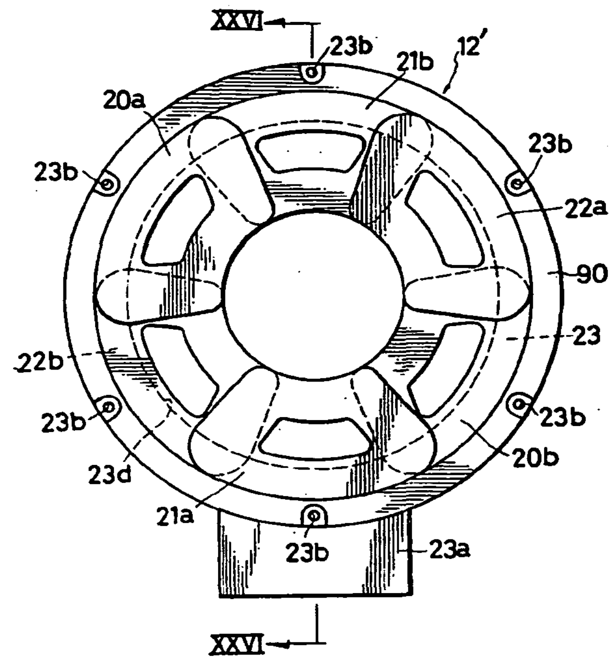

XXVI
23b
21b
12'
20a
23b
23b
22a
90
23
22b
23b
23b
20b
23d
21a
23b
23a
XXVI

FIG. 26

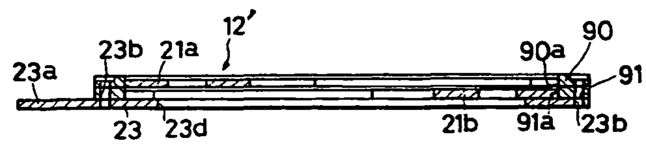

12'
90
23b
21a
90a
23a
91
23
23d
21b
91a
23b

FIG.27

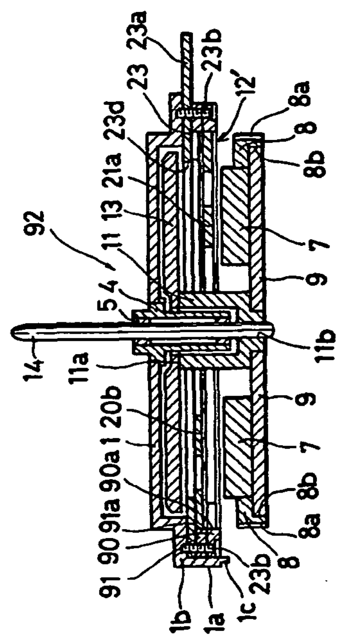
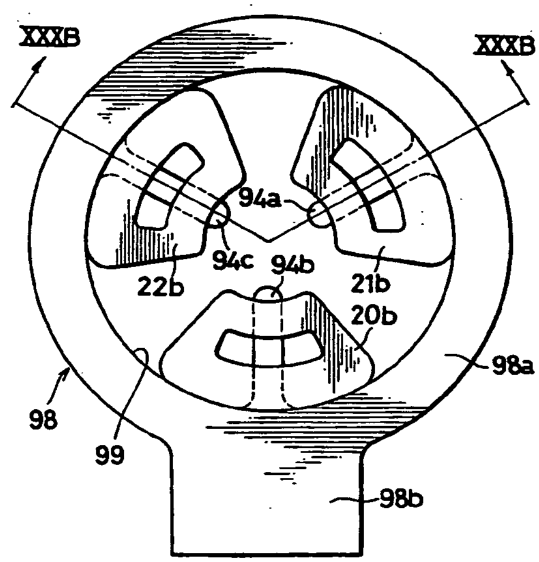

23a
23b
23
12'
8a
8
8b
23d
21a
13
11
92
7
9
5
4
14
11a
11b
20b
1
90a
91a
90
91
1b
1a
1c
23b
8
8a
8b
7
9

FIG. 29



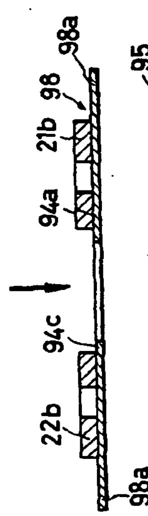


FIG.30 B

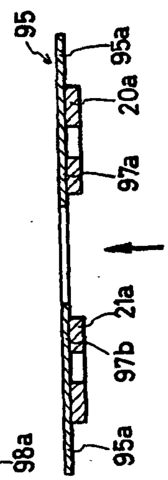


FIG.30A

FIG.31

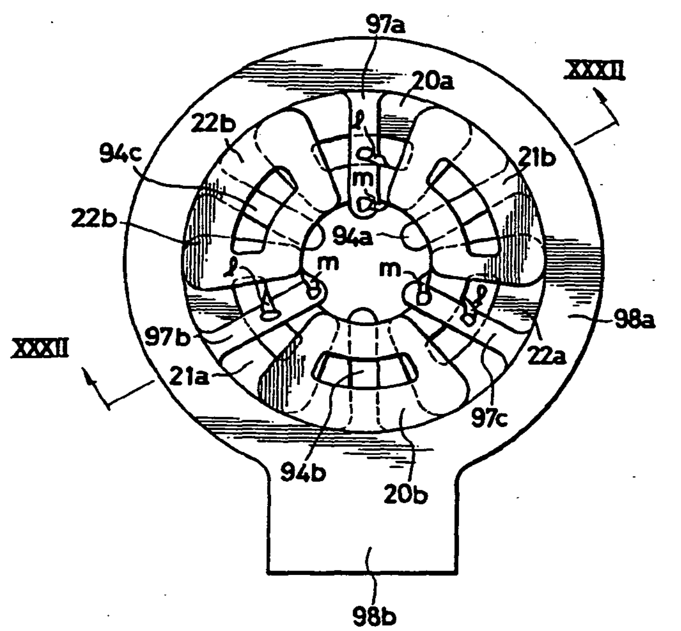

97a
20a
XXXII
22b
94c
21b
m
22b
94a
m
m
98a
97b
XXXII
22a
21a
97c
94b
20b
98b

FIG. 32

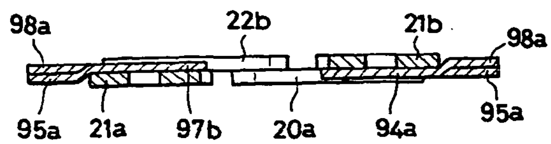

98a
22b
21b
98a
95a
21a
97b
20a
94a
95a

FIG.33

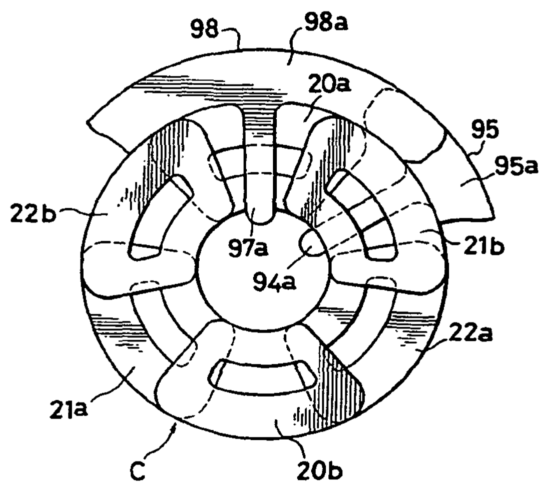

98
98a
20a
95
95a
22b
97a
94a
21b
22a
21a
C
20b

FIG.34

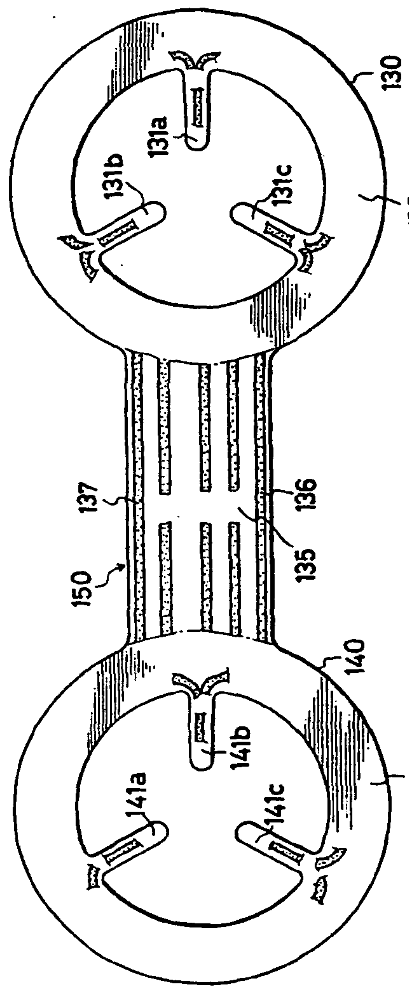

130
130a
131a
131b
131c
135
136
137
140
140a
141a
141b
141c
150

FIG.35

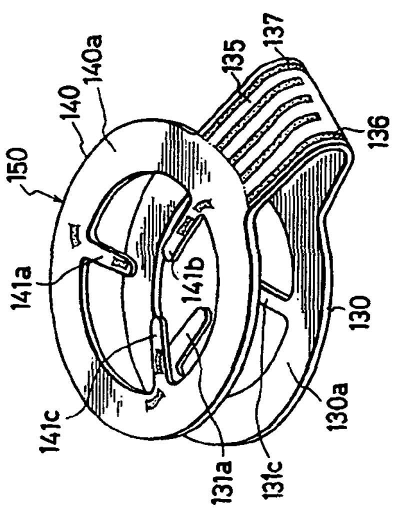
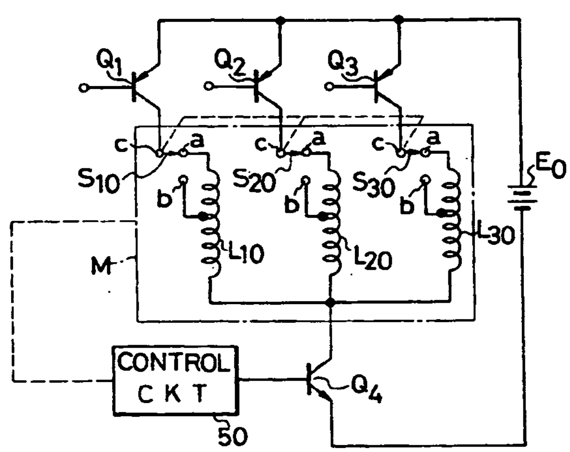


FIG.36


Q1
Q2
Q3
c
a
S10
b
c
a
S20
b
c
a
S30
b
L10
L20
L30
E0
M
CONTROL
C K T
50
Q4